Influence of sewing parameters on the energy consumption of the sewing machines

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ABSTRACT – REZUMAT

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The clothing industry due to the rapid changes in the technological and economical fields faces continuously new challenges like efficient machine and process settings' changes for individual production orders for smaller quantities; increased product and materials variety and increased competitiveness through higher quality and lower production costs.

Energy consumption is very important because, besides the varying costs (material, labour), the costs of energy are one of the key factors affecting the manufacturing costs, which is the main factor affecting the final price of the clothing products. It is well known that energy costs constitute 10–15 % of the overall manufacturing costs in the apparel industry.

In the present study, the correlation of the various sewing parameters with the energy consumption and thus the energy costs are examined. In order to obtain this goal, a data collection system has been designed in order to meet the needs and the nature of the measurements. Sewing experiments were carried out on different samples using various sewing parameters and the consumption of the electrical power was monitored. Additionally, the measurements obtained during the experiments were sent and stored in a computer for the processing of the signals and their statistical evaluation.

Keywords: *sewing parameters, energy consumption, efficiency, performance, sewing machines*

Influența parametrilor de coasere asupra consumului de energie al mașinilor de cusut

Industria de îmbrăcăminte, din cauza schimbărilor rapide din domeniile tehnologic și economic, se confruntă în continuu cu provocări noi, precum modificări eficiente ale setărilor echipamentelor și proceselor pentru comenzile individuale de producție în cantități mai mici; o varietate crescută de produse și materiale și creșterea competitivității prin calitate superioară și costuri de producție mai mici.

Consumul de energie este foarte important deoarece, pe lângă costurile variate (material, manoperă), costurile cu energia reprezintă unul dintre factorii cheie care influențează costurile de fabricație, fiind principalul factor care afectează prețul final al produselor de îmbrăcăminte. Este bine cunoscut faptul că aceste costuri reprezintă 10–15% din costurile totale de producție în industria de îmbrăcăminte.

În studiul de față, se analizează corelarea dintre diferiți parametri de coasere, consumul de energie și costurile energiei. Pentru a atinge acest scop, a fost conceput un sistem de colectare a datelor care să răspundă nevoilor și naturii determinărilor. Experimentele de coasere au fost efectuate pe diferite probe, folosind diverși parametri de coasere și a fost monitorizat consumul de energie electrică. În plus, determinările obținute în timpul experimentelor au fost trimise și stocate într-un computer pentru procesarea semnalelor și evaluarea statistică a acestora.

Cuvinte-cheie*: parametri de coasere, consum de energie, eficiență, performanță, mașini de cusut*

INTRODUCTION

The competitive character of clothing manufacturing enables continuous actions towards the improvement of several factors like the optimization of the process parameters, the use of new materials, the adaptation of the manufacturing concepts towards the quick response for small batches and new products. This trend poses certain requirements on the production systems and equipment: both have to be flexible and reliable. In the case of the equipment, it means shorter set-up times upon material changes and much more efficient quality assurance procedures.

The response to that critical situation using the traditional empirical machine set-up and process planning methods is difficult and it does not ensure the achievement of the goals. Better control and predictability of the processes are required. Additionally, in the new and thriving segment of technical textiles, defects may cause the failure of product functions. Also, they increase the demand for new methods providing more holistic and knowledge-based management and control of the processes [1]. In order to decrease the production costs, a general emphasis was given on the material and labour costs and they concentrate mainly on the different methods are applied for minimization. Energy costs aren't considered yet with these headings.

Energy consumption is an important issue for optimization, as, besides varying costs (material, labour), the cost of energy is one of the key factors forming the total manufacturing cost, thus determining the price of any article of clothing. It is well known that energy costs constitute some 10–15% of the overall manufacturing costs in the garment industry [2].

There are several studies correlating sewing speed, needle selection, needle penetration and withdrawal forces and energy consumption. Lojen published a study in 1995 about stitching velocity. Stitching velocity is one of the parameters in the technological operation of sewing which influence both total sewing time and quality of stitch form [3]. According to Stjepanovic, the selection of a suitable sewing needle was proved to be one of the most important parameters in the production of garments' joints. Needle thickness is an important parameter and should correspond to thickness, respectively surface mass of sewing material and sewing thread [4].

Rogale and Dragcevic have developed the first measurement and data acquisition system for sewing machines in 1998. The system was capable to measure simultaneously a number of parameters (sewing speed, average sewing speed, maximum sewing speed attained, sewing acceleration, number of stitches in a seam etc.). It could be also linked with some other measuring equipment for the investigation of other processing factors. It can rightly be considered a universal tool for investigating processing parameters in real in-plant conditions, and, as such, a necessary tool for clothing engineering [5].

Silva et al. have studied the compression force and the displacement waveforms from the presser foot bar, as well as the admissible displacement limits used to monitor (on- and offline) fabrics' feeding efficiency [6]. Rogale et al. studied the energy consumption of sewing machines in 2005. According to their study, consumption of electrical energy is of high importance in garment sewing processes and selection of a proper method of work can result in reducing the time necessary to perform the operations, simplification of the operation structure, higher average stitching speed and higher sewing machine utilization [2].

In 2006, Bayraktar and Kalaoğlu have developed an online measurement and monitoring system to measure dynamic yarn stresses and presser force during the sewing process [7]. Carvalho et al. aimed to develop real-time control and monitoring devices, as well as offline process planning tools for industrial sewing by evaluation of needle penetration forces [8].

The energy consumed during the sewing process is the biggest part of the total energy consumption for the garment industry. Needle penetration and withdrawal forces vary according to sewing parameters and the materials used. These forces contribute to the mechanical load of the machine and consequently to the total energy consumption. The present study approaches the energy consumption issue in a different frame. It is aimed to determine the effect of various sewing parameters such as fabric features, sewing needle size, seam length and sewing speed on the penetration and withdrawal forces and finally on the energy consumption. A measurement and data collection system were developed for the measurement of the energy consumption during the sewing process under variable sewing parameters.

The thorough study and the understanding of the factors affecting the energy consumption during the sewing process is the target of the paper because it is the main way to optimize it and to obtain the minimization of the energy costs. It is worth mentioning that even a small decrease of the energy consumed during the sewing process results in a huge amount of total energy saving if it will be considered that all over the world decades of millions of sewing machines are in daily operation. Therefore, the current study has an additional vision towards the respective environmental benefits.

MATERIALS AND METHOD

Materials

For the sewing experiments, three different types of knitted fabrics have been chosen; two knitted-based laminated fabrics with different lamination characteristics. The laminated fabrics are affecting the sewing machine load because of fabric hardness and higher needle penetration force. Therefore, two different types of laminated single jersey fabric were compared with each other and also with a cotton jersey knitted fabric was used as reference material.

The fabric types used for the experiments are shown in figure 1.

The sewing experiments were made on a full automatic 301 lockstitch machine, equipped with a direct drive servo motor.

Two different needle sizes of the types DP*5 (134R) 80 Nm and DP*5 (134R) 110 Nm were used since the size of the needles is considered as one of the main sewing parameters. These needles have the same (SUK) needlepoint shape. A standard 150 dtex*2 core-spun PES sewing thread was used for all sewing experiments.

The physical characteristics and the properties of the fabrics were measured using instruments and testers

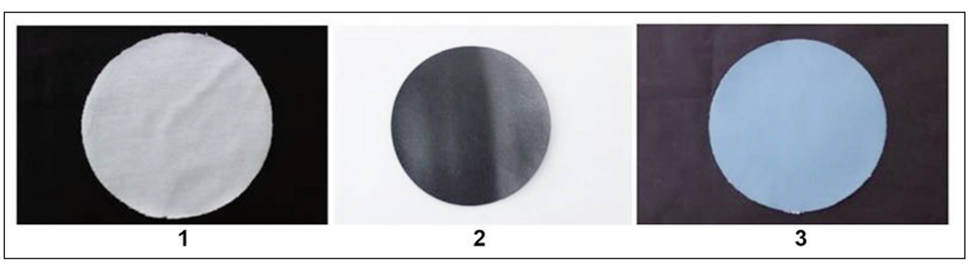

Fig. 1. Fabric types: *1* – 100% Cotton Single Jersey (CO); *2* – PES Single Jersey with PE-PUR lamination (PES-PE/PUR); *3* – PES Single Jersey with PUR lamination (PES-PUR)

like a precision balance, Shirley hardness tester, loop length and L&M Sewability tester for the measurement of the fabric weight per unit area, fabric density and sewability correspondingly. These values are related to machine sewing load and needle penetration force. Measurements were taken using these devices in order to correlate the increasing machine load with energy consumption.

Method

In this study, the effect of needle size, seam length, sewing speed and their interactions to energy consumption has been examined. The investigation was based on the use of the data logger system connected to the sewing machine. Factorial trials design was chosen for the design of the experiment.

The mechanical and physical properties of the fabrics were investigated in order to characterize the fabric types used in this study. After the definition of the fabric properties, sewing operations were performed with different parameters. Energy consumption was measured and the data were collected by the developed system. The data collected were analysed statistically, after the sewing experiments.

The sewing experiments were based on four variable groups:

• 3 different fabric types;
• 2 different needle sizes (80 and 110 Nm);
• 2 different seam lengths (20 and 40 cm);
• 2 different sewing speeds (1500 and 3000 rev/min).

Seam length and sewing speed values were kept constant through the control system of the sewing machine. After adjustments, 2 layers of fabrics have been sewn linearly, through lengthwise grainline (wales) direction. Electric energy data (operating current and voltage of the machine) were measured and collected under these different sewing conditions. Since the operating voltage is constant, the electric power and energy consumed have been estimated based on the measurement of the electric current.

A data collection system has been specially designed for the measurement of the actual electrical performance of the sewing machine under real conditions, during the sewing process. The system consists of the following units:

• Current sensor;
• Voltage sensor;
• Data logger unit;
• Interface and communication unit;
• Personal computer.

The current and voltage measuring and data collection system (data logger) were set up between the machine and the power supply during the sewing operations (figure 2). The data logger was designed to get 350 samples per second. A data cable was connecting the data logger and the computer for the data transfer. The data were transferred and saved in text format using the Hyperterminal program.

The stored data were imported into the Excel program for further data processing. The saved non-valid data before the start of the sewing operations and the corresponding data after the end of the sewing operations, which contain thread trimming and presser foot lifting, were deleted (figure 3). The average electrical current value was calculated for every single test and for each experimental group.

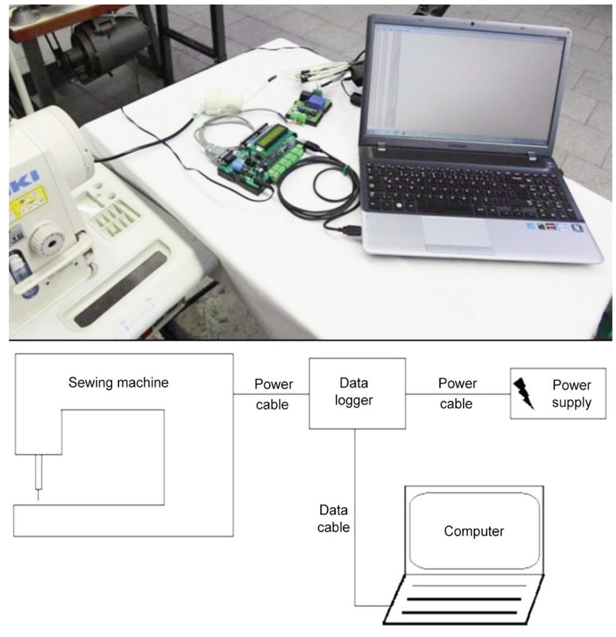

Fig. 2. General and schematic view of the data logging system

The measurements were repeated five times for each of the 24 fabric samples combinations according to the experiment design in order to perform the variation analysis. The statistical analysis of the 120 obtained waveforms corresponding to the respective sewing tests has been performed using PASW 25.0 software package.

RESULTS AND DISCUSSION

The technical characteristics of the three different fabric types used for the sewing experiments, such as fabric mass per unit area, the density of wales and courses and sewability values are shown in tables 1 and 2.

The average current values, used for statistical analysis, resulted from the measurements during the actual sewing process. The current fluctuation during the actual sewing process corresponds to area 1 in figure 3. The average current values given in table 3

Table 1

STRUCTURAL CHARACTERISTICS OF FABRICS

Sample	1	2	3
Fabric composition	CO	PES-PE/PUR	PES-PUR
Fabric mass per unit area (gr/m²)	144.15	194.7	376.2
Wales density (wales per cm)	14	13	11.5
Courses density (courses per cm)	21	17	8.5

Table 2

THE SEWABILITY VALUES OF FABRICS			
Sample	**1**	**2**	**3**
Fabric composition	CO	PES-PE/PUR	PES-PUR
Threshold value (gf)	50	50	150
Average sewability value	45.33	100	98.67
Average penetration force (gf)	118.67	446	234.33

include only the data of that area. The non-valid data before and after sewing operations corresponding to the thread trimming and presser foot lifting were filtered and removed before any calculation.

The average current values of the measurements on the five specimens per sample for the various combinations of fabric type, needle size, sewing speed and seam length are given in table 3.

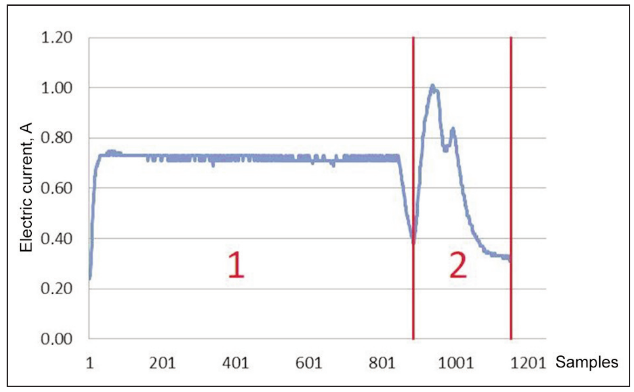

Fig. 3. Typical layout of the current waveform (testing group 1); actual measurements (1) and thread trimming-presser foot lifting area (2)

Table 4 shows the statistical data of the current values on the total of the 120 individual specimens for the various combinations of the independent variables.

Table 3

AVERAGE CURRENT PER EXPERIMENTAL GROUP						
Group	**Sample no.**	**Composition**	**Needle size (Nm)**	**Sewing speed (rev/min)**	**Seam length (cm)**	**Average current values (A)**
1	1	CO	80	1500	20	0.71
2	1	CO	80	1500	40	0.73
3	1	CO	80	3000	20	1.10
4	1	CO	80	3000	40	1.14
5	1	CO	110	1500	20	0.76
6	1	CO	110	1500	40	0.77
7	1	CO	110	3000	20	1.11
8	1	CO	110	3000	40	1.16
9	2	PES - PE/PUR	80	1500	20	0.71
10	2	PES - PE/PUR	80	1500	40	0.70
11	2	PES - PE/PUR	80	3000	20	1.09
12	2	PES - PE/PUR	80	3000	40	1.13
13	2	PES - PE/PUR	110	1500	20	0.75
14	2	PES - PE/PUR	110	1500	40	0.76
15	2	PES - PE/PUR	110	3000	20	1.10
16	2	PES - PE/PUR	110	3000	40	1.14
17	3	PES - PUR	80	1500	20	0.73
18	3	PES - PUR	80	1500	40	0.72
19	3	PES - PUR	80	3000	20	1.10
20	3	PES - PUR	80	3000	40	1.15
21	3	PES - PUR	110	1500	20	0.75
22	3	PES - PUR	110	1500	40	0.75
23	3	PES - PUR	110	3000	20	1.11
24	3	PES - PUR	110	3000	40	1.17

Table 4

DESCRIPTIVE STATISTICS OF THE CURRENT VALUES						
Parameter	**No. of specimens**	**Min value**	**Max value**	**Average**	**Std. Dev.**	**Variance**
Electric current (A)	120	0.69	1.18	0.93	0.20	0.04

Table 5

ANALYSIS OF VARIANCE	
Data Source	**Significance p**
Corrected Model	0
Intercept	0
Fabric type	0
Needle size	0
Sewing speed	0
Seam length	0
Fabric type * Needle size * Sewing speed * Seam length	0.003
Fabric type * Needle size * Sewing speed	0
Fabric type * Needle size * Seam length	0.684
Fabric type * Sewing speed * Seam length	0.003
Needle size * Sewing speed * Seam length	0.46
Fabric type * Needle size	0
Fabric type * Sewing speed	0.022
Fabric type * Seam length	0.145
Needle size * Sewing speed	0
Needle size * Seam length	0.051
Sewing speed * Seam length	0

The univariate analysis of variance is presented in table 5 and from the data given; the significant influence of the parameters and the combinations of them is resulting.

The following parameter combinations correspond to higher values of the significance p:

- Needle size & Fabric type & Seam length $p = 0.684$
- Needle size & Sewing speed & Seam length $p = 0.460$
- Seam length & Fabric type $p = 0.145$
- Needle size & Seam length $p = 0.051$

meaning that their interactions are insignificant at the error level of 5%, i.e., they don't have any effect on current values. Nevertheless, a p-value of 0.051 for the "Needle size & Seam length" effect is sufficient to suggest that this interaction has no effect on electric current values, but the characterization can be considered as marginal.

On the contrary, the significance p has lower values for the following parameters and their combinations:

- Needle size $p = 0$
- Sewing speed $p = 0$
- Seam length $p = 0$
- Fabric type $p = 0$
- Fabric type & Needle size & Sewing speed & Seam length $p = 0.003$
- Fabric type & Needle size &Sewing speed $p = 0$
- Fabric type & Sewing speed & Seam length $p = 0.003$
- Fabric type &Needle size $p = 0$
- Needle size &Sewing speed $p = 0$
- Sewing speed & Seam length $p = 0$.

These p values indicate that the related factors are important at the level of 1% ($p < 0.01$), i.e., these variables affect the dependent value of the electric current.

Additionally, for one combination of parameters

- Fabric type &Sewing speed $p = 0.022$

the p-value shows that this interaction has an effect on the electric current value at a 5% error level.

According to the previous detection of the most significant factors, an investigation of the corresponding experimental results has been made. The obtained data have been studied in order to examine the nature of the dependence between the various factors and the energy consumption on the physical level apart from the statistical one.

In terms of nominal amplitude current values, the most intense variation was caused by the change of the sewing speed. By the increase of the sewing speed, a respective increase of the electric current appears. A representative example is given in figure 4. In qualitative terms double sewing speed doubles, the nominal electric current.

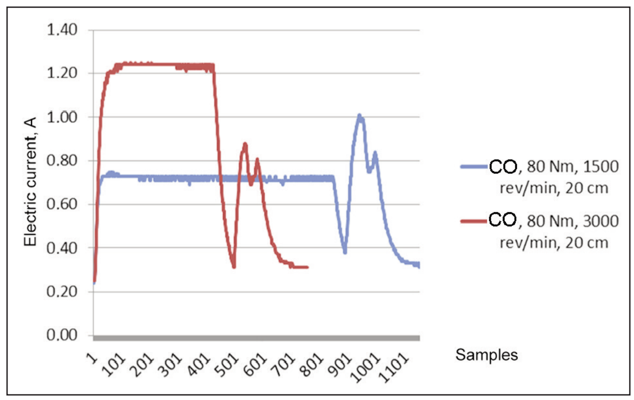

Fig. 4. Electric current vs sewing speed

This finding at a first glance is of minor importance since the energy consumed in both cases is the same, since the double speed and the double electric current consumption results in the completion of the sewing phase in half of the time needed for the low speed. However, a more detailed quantitative investigation gives interesting results. In the following table 6, I_{1500} and I_{3000} denote the electric current consumption of the sewing machine at 1500 and 3000 revolutions per minute.

Table 6 presents the electric current consumption in different combinations of materials, needles and lengths for 1500 and 3000 rpm for every case. Although it was expected that the ratio I_{3000}/I_{1500} should be 2, however, the nature of the transient phenomena and the machine mechanical characteristics, mass and inertia results in a lower ratio of the currents. According to that data, the operation of the sewing machine at higher speeds for the same material, same needle and same sewing length is less energy-consuming.

Concerning the effects of seam length, the respective measurements are given in table 7. It is obvious that

Table 6

ELECTRIC CURRENT VS SEWING SPEED			
Parameters	I_{1500}(A)	I_{3000}(A)	I_{3000}/I_{1500}
CO, Needle: 80 Nm, Length: 20 cm	0.71	1.1	1.55
CO, Needle: 80 Nm, Length: 40 cm	0.73	1.14	1.56
CO, Needle: 110 Nm, Length: 20 cm	0.76	1.11	1.46
CO, Needle: 110 Nm, Length: 40 cm	0.77	1.16	1.51
PES – PE/PUR, Needle: 80 Nm, Length: 20 cm	0.71	1.09	1.54
PES – PE/PUR, Needle: 80 Nm, Length: 40 cm	0.7	1.13	1.61
PES – PE/PUR, Needle: 110 Nm, Length: 20 cm	0.75	1.1	1.47
PES – PE/PUR, Needle: 110 Nm, Length: 40 cm	0.76	1.14	1.50
PES – PUR, Needle: 80 Nm, Length: 20 cm	0.73	1.1	1.51
PES – PUR, Needle: 80 Nm, Length: 40 cm	0.72	1.15	1.60
PES – PUR, Needle: 110 Nm, Length: 20 cm	0.75	1.11	1.48
PES – PUR, Needle: 110 Nm, Length: 40 cm	0.75	1.17	1.56

Table 7

ELECTRIC CURRENT VS SEAM LENGTH			
Parameters	I_{20cm}(A)	I_{40cm}(A)	I_{20cm}/I_{40cm}
CO, Needle: 80 Nm, 1500 rpm	0.71	0.73	1.03
CO, Needle: 80 Nm, 3000 rpm	1.1	1.14	1.04
CO, Needle: 110 Nm, 1500 rpm	0.76	0.77	1.01
CO, Needle: 110 Nm, Length: 40 cm	1.11	1.16	1.05
PES – PE/PUR, Needle: 80 Nm, 1500 rpm	0.71	0.7	0.99
PES – PE/PUR, Needle: 80 Nm, 3000 rpm	1.09	1.13	1.04
PES – PE/PUR, Needle: 110 Nm, 1500 rpm	0.75	0.76	1.01
PES – PE/PUR, Needle: 110 Nm, 3000 rpm	1.1	1.14	1.04
PES – PUR, Needle: 80 Nm, 1500 rpm	0.73	0.72	0.99
PES – PUR, Needle: 80 Nm, 3000 rpm	1.1	1.15	1.05
PES – PUR, Needle: 110 Nm, 1500 rpm	0.75	0.75	1.00
PES – PUR, Needle: 110 Nm, 3000 rpm	1.11	1.17	1.05

the ratio of the electric current for the two different sewing lengths of 20 and 40 cm is close to the unity with marginal deviations of a maximum of 5%, which can be explained as belonging to the extent of the random occurring deviations and measurements errors.

It is shown in the following figure 5, the graph of the variation of the electric current of a representative testing case for Cotton, needle 110 Nm and 1500 rpm. During the use of different needles 80 and 110 Nm considerable variation of the average current consumption. The thicker the needles, the higher the mechanical resistance during the penetration of the needle, so the load on the machine and the average current is increased.

According to the data of table 8, it is verified that the electric current consumed when bigger needles are used is systematically higher than when a smaller needle is used. However, the increase of the mean power consumed is in the range of 1–9% (figure 6).

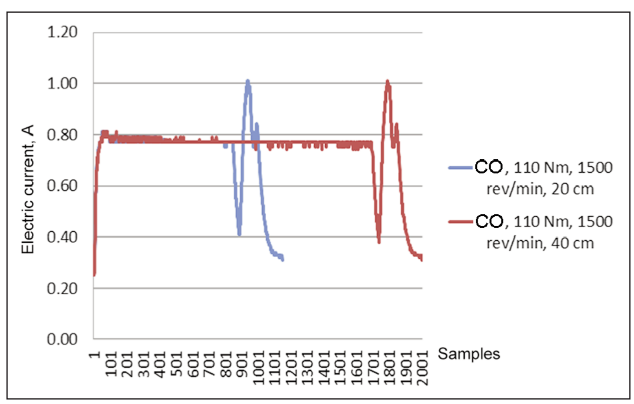

Fig. 5. Electric current vs seam length

The dependency of the electric current and consequently the power consumed depends also on the mass per unit area of the fabrics. Table 9 presents the related data.

The received data indicate that the electric current i.e., power consumed, is almost constant for the

Table 8

ELECTRIC CURRENT VS NEEDLE SIZE			
Parameters	I_{80Nm}(A)	I_{100Nm}(A)	I_{80Nm}/I_{100Nm}
CO, Length: 20 cm, 1500 rpm	0.71	0.76	1.07
CO, Length: 40 cm, 1500 rpm	0.73	0.77	1.05
CO, Length: 20 cm, 3000 rpm	1.1	1.11	1.01
CO, Length: 40 cm, 3000 rpm	1.11	1.16	1.05
PES – PE/PUR, Length: 20 cm, 1500 rpm	0.71	0.75	1.06
PES – PE/PUR, Length: 40 cm, 1500 rpm	0.7	0.76	1.09
PES – PE/PUR, Length: 20 cm, 3000 rpm	1.09	1.1	1.01
PES – PE/PUR, Length: 40 cm, 3000 rpm	1.13	1.14	1.01
PES – PUR, Length: 20 cm, 1500 rpm	0.73	0.75	1.03
PES – PUR, Length: 40 cm, 1500 rpm	0.72	0.75	1.04
PES – PUR, Length: 20 cm, 3000 rpm	1.1	1.11	1.01
PES – PUR, Length: 40 cm, 3000 rpm	1.15	1.17	1.02

Table 9

ELECTRIC CURRENT VS MASS PER UNIT AREA			
Parameters	**CO**	**PES - PE/PUR**	**PES - PUR**
Length: 20 cm, 1500 rpm, Needle 80 Nm	0.71	0.71	0.73
Length: 20 cm, 1500 rpm, Needle 110 Nm	0.76	0.75	0.75
Length: 20 cm, 3000 rpm, Needle 80 Nm	1.1	1.09	1.1
Length: 20 cm, 3000 rpm, Needle 110 Nm	1.11	1.1	1.11
Length: 40 cm, 1500 rpm, Needle 80 Nm	0.73	0.7	0.72
Length: 40 cm, 1500 rpm, Needle 110 Nm	0.73	0.7	0.75
Length: 40 cm, 3000 rpm, Needle 80 Nm	1.14	1.13	1.15
Length: 40 cm, 3000 rpm, Needle 110 Nm	1.11	1.1	1.11

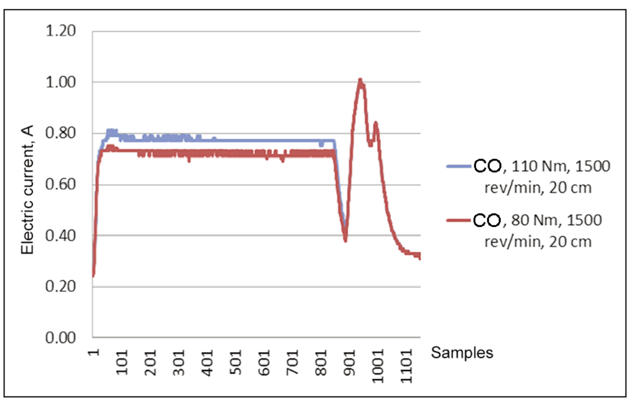

Fig. 6. Electric current vs needle size

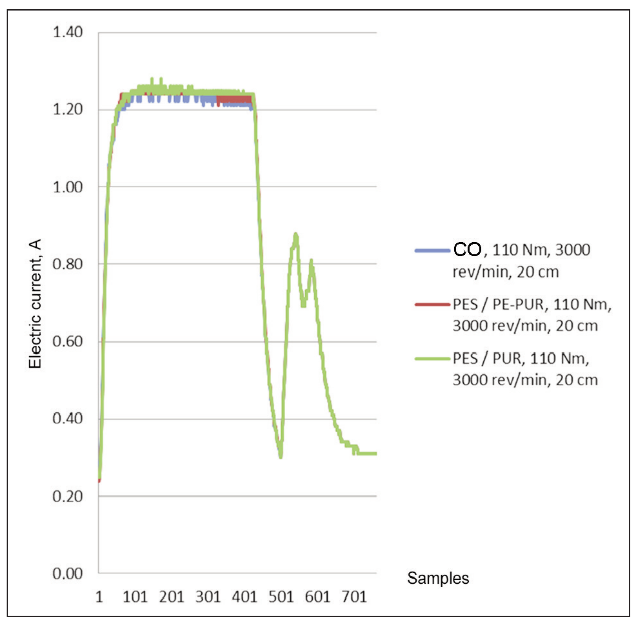

Fig. 7. Electric current vs fabric type

three categories of fabrics and for every combination of the other parameters. It seems that the mass of the moving parts of the sewing machine and the related inertia is of a size that permits the operation of the sewing machine in a sense that the load variations due to the different mass per unit area values do not affect considerably the power consumption (figure 7). In the above graph of a representative case (3000 rpm, 20 cm sewing length and needle type 110Nm) the similarity of the three curves is obvious. That similarity covers not only the steady-state regions but also the transient phenomena.

Studies in the literature have focused on the correct material matching (especially thread – fabric – sewing needle). In this study, the effects of the correct material and parameter selection on energy consumption were examined besides the material matching before sewing. Material selection is more than just an issue affecting production quality. The correct use of energy resources in increasing production rates is important in terms of both production costs and environmentally friendly production.

CONCLUSION

The sewing tests have included the total of the major parameters influencing the operation of the sewing machine. A general result of the evaluation and the statistical elaboration of the power measurements indicate that the sensitivity of the electric power versus the various parameters is extremely limited. The only valuable difference comes in the case of the sewing speed, where the higher speed results in lower power consumption.

The nature of the results and the evaluation of the data received, enable the further investigation of the process and it promotes the importance of the electronic measurement system developed. The system made possible the detection of the real operating conditions of the sewing machine and it will be used in future experiments.

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